FACILITATING COMMUNICATION OF DATA SIGNALS ON ELECTRIC POWER SYSTEMS

Technical Field of the Invention

The present invention relates to data communications, and more particularly to broadband data communication systems using underground and aerial electrical power cables.

Background of the Invention

Recently, several technologies that provide broadband data access have entered the market. These technologies include digital subscriber lines (DSL), cable modems, and wireless networks, among others. Another emerging technology uses existing electrical power distribution networks to carry high-frequency data signals to and from individual customer premises. Such systems may be referred to throughout as "power line communication systems." Because electrical power distribution networks were designed to carry low-frequency high-voltage signals, however, transmitting higher frequency data signals often face obstacles not confronted by their lower frequency counterparts.

Many components create such obstacles to the higher frequency data signal. One particular element in the electrical power distribution network that creates a particular hindrance to the data signal is the electrical transformer. The transformer is an integral element in the electrical power distribution system that has been designed to efficiently step-down voltage to values consistent with customer equipment, while providing the

necessary isolation and protection from higher voltage values. However, the efficiencies that have been designed to handle the voltage signals often have a detrimental consequence for the previously unanticipated transmission of data signals. Therefore, while the transformer provides a critical function for the transmission of low frequency power, it often creates an obstacle in the transmission of higher frequency data signals.

One particular impediment to the transmission of data signals is created by the inherent characteristics of the transformer itself. Typically, the construction of a transformer is such that its characteristic impedance for higher frequency data signals is significantly lower than the impedance encountered on the customer premise side of the transformer (*e.g.*, local distribution lines and customer premise equipment). As a result, if a communications signal is injected at the transformer, a significant portion of the higher frequency data signal follows the path of least resistance directly into the transformer, instead of ideally traveling over the distribution lines and onto the customer premise. As a result, a great deal of the data signal's strength is lost to the transformer and never reaches the customer premise. This condition is found in most transformer units because the electrical power distribution network, of course, was designed without the concern of transmitting higher frequency data signals.

Therefore, there is a need to reduce the loss of the higher frequency data signals communicated on the electrical power distribution system.

Summary of the Invention

The invention includes a method, system, and device for communicating a data signal on an electric power system. The inventive method includes communicating the data signal to the electric power system, and modifying the characteristics of the electric power system to reduce the data signal communicated to an electrical component located on the electric power system without substantially reducing a voltage signal. The method further includes communicating the data signal to a customer premise. The electrical component may include, for example, an electrical transformer. The modification of the characteristics of the electric power system may include increasing an impedance imposed by the transformer on the data signal. The impedance may be increased by increasing inductive properties of the transformer, for example, by using an inductor and/or adding one or more ferrite cores to the electric power system. The method also may increase an impedance from the transformer to a point at which the data signal is provided to the network. The inventive method also may apply to other electrical components such as a capacitor bank, a switch tap, a service entrance, a voltage sensing device, and an electrical measurement device. The data may have a frequency substantially in the range of 1 to 100 Mega Hertz, while the voltage signal may have a frequency substantially in the range of 0 to 100 Hertz.

Brief Description of the Drawings

Other features of the invention are further apparent from the following detailed description of the embodiments of the invention taken in conjunction with the accompanying drawings, of which:

Figure 1 is a block diagram of an electric power and data transmission system;

Figures 2A and 2B provide a circuit diagram of the electric power and data transmission system;

Figure 3 is a block diagram further detailing the power line communications system, according to the invention;

Figure 4 is a flow diagram of a method of transmitting a data signal on an electric power system, according to the invention; and

Figure 5 is a block diagram detailing one example of a blocking device.

Detailed Description of the Invention

Overview of Electric Power Transmission/Distribution System

Figure 1 is a block diagram of an electric power and data transmission system 100. Generally, electric power and data transmission system 100 has three major components: the generating facilities that produce the electric power, the transmission network that carries the electric power from the generation facilities to the distribution points, and the distribution system that delivers the electric power to the consumer. As shown in Figure 1, a power generation source 101 is a facility that produces electric

power. Power generation source 101 includes a generator (not shown) that creates the electrical power. The generator may be a gas turbine or a steam turbine operated by burning coal, oil, natural gas, or a nuclear reactor, for example. In each case, power generation source 101 provides a three-phase AC power. The AC power typically has a voltage as high as approximately 25,000 volts.

A transmission substation (not shown) then increases the voltage from power generation source 101 to high-voltage levels for long distance transmission on high-voltage transmission lines 102. Typical voltages found on high-voltage transmission lines 102 range from 69 to in excess of 800 kilovolts (kV). High-voltage transmission lines 102 are supported by high-voltage transmission towers 103. High-voltage transmission towers 103 are large metal support structures attached to the earth, so as to support the transmission lines and provide a ground potential to system 100. High-voltage transmission lines 102 carry the electric power from power generation source 101 to a substation 104.

Generally, a substation acts as a distribution point in system 100 and provide a point at which voltages are stepped-down to reduced voltage levels. Substation 104 converts the power on high-voltage transmission lines 102 from transmission voltage levels to distribution voltage levels. In particular, substation 104 uses transformers 107 that step down the transmission voltages from the 69-800 kV level to distribution voltages that typically are less than 35 kV. In addition, substation 104 may include an electrical bus (not shown) that serves to route the distribution level power in multiple directions. Furthermore, substation 104 often includes circuit breakers and switches (not

shown) that permit substation 104 to be disconnected from high-voltage transmission lines 102, when a fault occurs on the lines.

Substation 104 typically is connected to at least one distribution transformer 105. Distribution transformer 105 may be a pole-top transformer located on a utility pole, a pad-mounted transformer located on the ground, or a transformer located under ground level. Distribution transformer 105 steps down the voltage to levels required by a customer premise 106, for example. Power is carried from substation transformer 107 to distribution transformer 105 over one or more distribution lines 120. Power is carried from distribution transformer 105 to customer premise 106 via one or more service lines 113. Voltages on service line 113 typically range from 240 volts to 440 volts. Also, distribution transformer 105 may function to distribute one, two or all three of the three phase currents to customer premise 106, depending upon the demands of the user. In the United States, for example, these local distribution transformers typically feed anywhere from 1 to 10 homes, depending upon the concentration of the customer premises in a particular location.

Distribution transformer 105 also may be in communication with a power line bridge 121. Power line bridge 121 facilitates the transmission of data to electric power and data transmission system 100 over a data communication line 122. Power line bridge 121 may receive such data from a content server 111 over the Internet 112 via a data transmission line 114. Although not shown in Figure 1, it should be appreciated that power line bridge 121 may receive data using a number of other techniques including wireless network transmission, for example. Also, power line bridge 121 may receive

data that previously has been placed on electric power and data transmission system 100 at distribution line 120 and/or at high-voltage transmission lines 102, for example. In this way, data signals may be provided to customer premise 106 via a service line 113, which typically is used to carry electrical power from distribution transformer 105 to customer premise 106. Typically, these data signals will be in a different frequency range, usually higher, than the electrical power traditionally provided over service line 113.

Transmitting Data Over the Electric Power Transmission/Distribution System

Transmitting the higher frequency data signals to customer premise 106 over service line 113 requires overcoming certain impediments inherent in electric power and data transmission system 100. Figures 2A and 2B provide a circuit diagram of part of electric power and data transmission system 100, and further details certain impediments faced by the data signal. It should be appreciated that the circuit diagrams illustrated in Figures 2A and 2B have been simplified for the purposes of clarity and brevity. In practice, many other circuit features may be required to fully describe the system.

As shown in Figure 2A, power line bridge 121 is in a parallel circuit arrangement with both distribution transformer 105 and customer premise 106. Furthermore, data communication line 122 couples power line bridge 121 with distribution transformer 105, and service line 113 couples power line bridge 121 with customer premise 106. It follows, therefore, that the impedance of distribution transformer 105, customer premise 106, and service line 113 also will each be in parallel with power line bridge 121. Although power line bridge 121 is shown in parallel with distribution transformer 105

and customer premise 106, it should be appreciated that other circuit configurations also are contemplated by the invention, depending upon the precise nature of the power line bridge device. For example, the invention applies equally where power line bridge 121 is in series with customer premise 106 and/or with distribution transformer 105.

Figure 2B provides a circuit diagram of the corresponding impedances of the circuit shown in Figure 2A. As shown in Figure 2B, a first impedance, Z_t, represents the inherent impedance that the higher frequency data signal faces from distribution transformer 105, itself. A second impedance, Z_l, represents the impedance that the higher frequency data signal faces on the load side of distribution transformer 105. In particular, Z_l may comprise the impedance caused by a combination of many elements, including the load at customer premise 106 and the characteristic impedance of service line 113, for example.

The precise values of these impedances will vary widely depending upon location-specific variables, including equipment (*e.g.,* transformer make and model) and the type of customer premise (*e.g.,* residential, commercial, and industrial). Regardless of their precise values, however, basic principles of electrical theory well known to those skilled in the art dictate that when Z_l is significantly greater than Z_t, the data signal will follow the path of least resistance and be shunted significantly over distribution transformer 105. As a result, a significant portion of the data signal will be lost in distribution transformer 105 and thus be prevented from being transmitted to customer premise 106, as desired. Therefore, in order to maximize the data signal provided to

inductances of the transformer can partially mitigate the adverse effect of the capacitance, these inductances are typically small (*i.e.*, less than 600 nanohenries). Therefore, the impedance is dominated by the capacitance of the transformer's windings. Accordingly, the capacitance of the transformer windings create a path of least resistance, and thus cause a significant loss of the higher frequency data signal by diverting the data signal away from customer premise 106.

Figure 3 is a block diagram further detailing the relevant portions of electric power and data transmission system 100. It should be appreciated that other components may be required to transmit a data signal over electric power and data transmission system 100. However, the components depicted in the block diagram of Figure 3 are shown as such for purposes of clarity and brevity. Also, it should be appreciated that components other than distribution transformer 105 are contemplated by the invention.

As shown in Figure 3, power line bridge 121 is in communication with Internet 112 and with distribution line 120. Power line bridge 121 also is in communication with service line 113. Power line bridge 121 may receive a data signal directly from Internet 112 and provide it to customer premise 106. Also, power line bridge 121 may receive a data signal from distribution line 120. In this case, for example, distribution line 120 may operate as a local area network or wide area network to carry data signals. Where the data signal is provided over distribution line 120, power line bridge 121 provides a communication path over data communication line 122 and around distribution transformer 105. In either case, power line bridge 121 provides the data signals to service line 113, and onto customer premise 106.

inductances of the transformer can partially mitigate the adverse effect of the capacitance, these inductances are typically small (*i.e.,* less than 600 nanohenries). Therefore, the impedance is dominated by the capacitance of the transformer's windings. Accordingly, the capacitance of the transformer windings create a path of least resistance, and thus cause a significant loss of the higher frequency data signal by diverting the data signal away from customer premise 106.

Figure 3 is a block diagram further detailing the relevant portions of electric power and data transmission system 100. It should be appreciated that other components may be required to transmit a data signal over electric power and data transmission system 100. However, the components depicted in the block diagram of Figure 3 are shown as such for purposes of clarity and brevity. Also, it should be appreciated that components other than distribution transformer 105 are contemplated by the invention.

As shown in Figure 3, power line bridge 121 is in communication with Internet 112 and with distribution line 120. Power line bridge 121 also is in communication with service line 113. Power line bridge 121 may receive a data signal directly from Internet 112 and provide it to customer premise 106. Also, power line bridge 121 may receive a data signal from distribution line 120. In this case, for example, distribution line 120 may operate as a local area network or wide area network to carry data signals. Where the data signal is provided over distribution line 120, power line bridge 121 provides a communication path over data communication line 122 and around distribution transformer 105. In either case, power line bridge 121 provides the data signals to service line 113, and onto customer premise 106.

Distribution transformer 105 has both primary attachment lugs 303 and secondary attachment lugs 304. Primary attachment lugs 303 are located on the "supply" side or primary side of distribution transformer 105 and permit distribution transformer 105 to receive power, for example, from substation transformer 107. Secondary attachment lugs 304 are located on the "load" side or secondary side of distribution transformer 105 and permit distribution transformer 105 to provide power, for example, to customer premise 106. Although two attachment lugs each are shown on the primary and secondary side of distribution transformer 105 for the purpose of clarity and brevity, it should be appreciated that any number of attachment points may be available.

Each of secondary attachment lugs 304 is in communication with blocking devices 301 and 302. Blocking devices 301 and 302 also are in communication with customer premise 106 and power line bridge 121. Blocking devices 301 and 302 operate to modify the characteristics of electric power and data transmission system 100 so as to reduce the portion of data signal transmitted to distribution transformer 105, and to correspondingly increase the amount of data signal provided to customer premise 106 over service line 113. Therefore, when power line bridge 121 provides a data signal to data communication line 122, blocking devices 301 and/or 302 operate to resist the flow of the data signal to distribution transformer 105 and to persuade the flow of the data signal to customer premise 106.

Although two blocking devices, 301 and 302 are shown in Figure 3, it should be appreciated that any number of blocking devices may be used, depending upon the particular application. For example, in certain applications the data signal may be sent

over just one service line 113, and so perhaps just one corresponding blocking device is required. Alternatively, in certain applications data signal may be sent over two or more service lines, and therefore one or more blocking devices may be required. Moreover, in certain applications, a blocking device may not be required for each service line that transmits a data signal.

Although blocking devices 301 and 302 are shown in Figure 3 as located between distribution transformer 105 and customer premise 106, it should be appreciated that these devices similarly may be located in other locations. Also, blocking devices 301 and 302 may be located in series on the supply side of distribution transformer 105, for example, in communication with primary attachment lugs 303. Therefore, the invention is not limited to a particular location of the blocking devices within the electrical power system.

Although the data signal may be provided at any point in electric power and data transmission system 100, in practice, it may be desirable for the data signal to be provided at a point that is relatively free of signal interference. Such signal interference typically is created by traditional electrical power system components, like electrical transformers and parallel capacitor banks, for example. Typically, therefore, the data signal is coupled at a point located between local distribution transformer 105 and customer premise 106. Often, economic and ease-of-installation concerns dictate that the coupling take place as close to distribution transformer 105 as possible, typically on the customer premise side of the transformer (*i.e.,* the transformer secondary side).

Also, it should be appreciated that the particular method used to resist the flow of the data signal to the distribution transformer and to persuade the flow of the data signal to the customer premise is not limited to a particular technique. The invention contemplates various techniques based on the particular characteristics of the data signal, and the manufacture of the transformer. For example, in one embodiment, blocking devices 301 and 302 may resist the flow of the data signal to the distribution transformer by increasing the inductance of distribution transformer 105 as seen by the data signal.

Increasing the inductive properties of distribution transformer 105 may be desirable where the data signal operates at a significantly higher frequency than the traditional power signal that typically operates at approximately 50 to 60 Hz. In this embodiment, increasing the inductance of the distribution transformer 105 as seen by the data signal serves the dual purpose of impeding the higher frequency data signal from entering distribution transformer 105, while continuing to provide a lower impedance to the traditional lower frequency power signal.

Figure 4 is a flow diagram of a method 400 of transmitting a data signal on electric power and data transmission system 100. In step 401, power line bridge 121 communicates the data signal to electric power and data transmission system 100 via data communication line 122. As discussed, the data signal may be provided at any point in electric power and data transmission system 100.

In step 402, it is determined whether the operating frequency of the data signal is significantly larger than the frequency of the power signal. Typically, in wideband data transmission scenarios the data signal is in the range of 1 MHz to 100 MHz and the

voltage signal is approximately 60 Hz. In this instance, one method for preventing the data signal from being sent to distribution transformer 105 is by using a blocking device to effectively increase the inductance of the distribution transformer 105 as seen by the data signal, in step 403. Such an increase in inductance operates to prevent the data signal from flowing to distribution transformer 105, while permitting the voltage signal to flow without additional loss of power.

It should be appreciated that other methods for preventing the flow of the data signal to distribution transformer 105 are contemplated. For example, in step 402, where the operating frequency of the data signal is not significantly larger than the frequency of the voltage signal, other techniques may be used to impede the flow of the data signal to distribution transformer 105 without substantially influencing the flow of the voltage signal. These specific techniques will be based on the characteristics of the data signal and the voltage signal, as well as the desired power transmission quantities of the data and voltage signals. In either case, in step 405, the data signal and the voltage signal are communicated with customer premise 106.

Figure 5 is a block diagram detailing one example of blocking device 301. Although not illustrated in Figure 5, it should be appreciated that blocking device 302 may be similarly configured. Moreover, while blocking device 301 is shown in Figure 5 having an inductive element, it should be equally appreciated that other possible configurations are contemplated, depending upon the characteristics of electric power and data transmission system 100, as well as the characteristics of the data signal and voltage signal.

As shown in Figure 5, blocking device 301 includes an input port 501 and an output port 502. In one embodiment, an inductive element 503 is in communication with input port 501 and output port 502. Input port 501 receives the voltage signal from distribution transformer 105 via service line 113. Output port 502 provides the voltage signal to customer premise 106 via service line 113. In addition, output port 502 may receive a portion of the data signal provided by power line bridge 121 via data communication line 122.

Inductive element 503 in blocking device 301 is selected to have properties that reduce the portion of the data signal directed to distribution transformer 105, and to correspondingly increase the portion of the data signal provided to customer premise 106. Accordingly, the characteristics of the inductive element 503 will vary with the particular circumstances. For example, where the voltage signal operates at or near 60 Hz, and where the data signal has a frequency substantially in the range of 1 MHz to 100 MHz, inductive element 503 may be approximately 8 microhenries. This one example of a value for inductive element 503 provides an impedance of 50 ohms for 1 MHz signals, yet only 3 milliohms for 60 Hz signals, for example. Therefore, the 8 microhenry inductive element provides a low impedance for the 60 Hz voltage signal allowing unimpeded flow of electric power, while providing a higher impedance for the 1 MHz data signal and impeding the flow of the data signal into distribution transformer 105.

As is well known to those skilled in the art, because a single winding of a conductor passing through a ferrite core creates an inductance greater than that of the conductor alone, it may be desirable to vary the inductive properties of the transformer as

seen by the data signal by applying such a configuration to one or more components of distribution transformer 105. Moreover, the size and magnetic properties of the ferrite material may be manipulated to ensure the desired inductance is created.

Although an inductive element 503 has been described in Figure 5, it should be appreciated that the invention is not so limited. In particular, other elements, perhaps non-inductive or partially so, may be used to restrict the flow of the data signal to distribution transformer 105. The types of other elements used may vary depending on the characteristics of the data signal and the voltage signal, the permissible loss of the voltage signal, and the required power level of the data signal to be transmitted to customer premise 106. The types of elements may also vary depending on the characteristics of the electrical components, the type of compoents (*e.g.,* distribution transformer and capacitor bank) and the nature of the portion of the electrical power system under consideration (*e.g.,* medium voltage and high voltage).

As discussed, the secondary attachment lugs of distribution transformer 105 provide one possible location to attach a blocking device to electric power and data transmission system 100. This is particularly true for underground power distribution systems, where distribution transformer 105 is a pad-mount transformer, because secondary attachment lugs 304 of distribution transformer 105 are one of the few locations where service line 113 is not underground, and thus readily accessible. In this embodiment, therefore, it may be practically desirable from an implementation perspective to effectively increase the impedance, for example, of distribution transformer 105 by locating a ferrite material, perhaps in the form of a blocking device,

around secondary attachment lugs 304. In particular, the ferrite material may be constructed such that it clamps over service line 113 at distribution transformer 105 and/or at secondary attachment lug 304. This technique provides a method for dissuading the data signal from flowing to distribution transformer 105, while facilitating modification and installation to a transformer that is already in service in the field.

Although this is one possible technique, it should be appreciated that other techniques are contemplated by the invention. For example, a ferrite core could be added to the internal leads located between the core of distribution transformer 105 and its primary 303 or secondary 304 attachment lugs. Because distribution transformer 105 typically is required to be sealed to prevent weather conditions from effecting its operation, this modification typically would take place at the time of manufacture, and provides a possible additional noise suppression feature to the transformer.

In addition to facilitating the flow of the data signal to customer premise 106, inductive element 503 may operate to prevent electromagnetic interference or noise that often propagates between the primary and secondary windings of distribution transformer 105. As a result, the electromagnetic interference typically provided on service line 113 by distribution transformer 105 may be prevented from being coupled via service line 113 to customer premise 106, disrupting appliances or communications equipment in customer premise 106. Also, electromagnetic noise generated by customer premise 106 may be prevented from entering the secondary windings of distribution transformer 105 and being carried onto distribution line 120 where it may be radiated and undesirably interfere with users of the radio frequency spectrum.

The invention is directed to a system and method for communicating a data signal on an electric power system. It is noted that the foregoing examples have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the invention. While the invention has been described with reference to certain embodiments, it is understood that the words that have been used herein are words of description and illustration, rather than words of limitation. For example, the invention may apply equally to other electrical system components other than a transformer, as well as being applied to any part of electric power and data transmission system 100. For example, although the invention is described with respect to a transformer, it should be appreciated that the invention may be applied equally to other electrical components such as capacitor banks, switch taps, service entrances, voltage sensing devices, and electrical measurement equipment. Further, although the invention has been described herein with reference to particular means, materials and embodiments, the invention is not intended to be limited to the particulars disclosed herein. Rather, the invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims.

Those skilled in the art, having the benefit of the teachings of this specification, may effect numerous modifications thereto and changes may be made without departing from the scope and spirit of the invention in its aspects. Those skilled in the art will appreciate that various changes and adaptations of the invention may be made in the form and details of these embodiments without departing from the true spirit and scope of the invention as defined by the following claims.